Proposal for Generic R&D on EIC Detectors

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1. Introduction

We would like to propose several R&D projects, which we think, might be useful in the final design and realization of the Electron Ion Collider (EIC) detector systems. At this stage, we would like to pursue several initial tests and feasibility analysis of various detector concepts we have developed for hadron and lepton colliders over the past years with consideration of minimal funding request. Once the concepts are validated, a proposal for construction and testing of detector prototypes will be prepared.

2. Electromagnetic Calorimetry

We strongly believe that the imaging calorimetry suitable with the Particle Flow Algorithms (PFAs) is the most beneficial system for any collider detector. CMS [1] has benefited from the application of PFAs in various analyses although none of the CMS detectors were optimized for PFAs. EIC could be a pioneering effort to utilize PFA-compatible detector systems that would provide an unprecedented insight to the rich physics the EIC has to offer.

As the active medium of EIC electromagnetic calorimeters both in the barrel and the forward regions, we would like to study the secondary emission modules.

In a Secondary Emission (SE) calorimeter ionization detector module, Secondary Emission electrons (SEe) are generated from an SE surface/cathode/"dynodes", when charged hadronic or electromagnetic particles (shower particles) penetrate an SE sampling module either placed between absorber materials (Fe, Cu , Pb, W etc) in calorimeters, or as a homogeneous calorimeter consisting entirely of dynode sheets as the absorbers. An SE cathode – as on PMT dynodes - is a thin (10-50 nm thick) film. These films are typically simple metal-oxides Al_2O_3, MgO, CuO/BeO, or other higher yield materials. The simple native oxide on Al produces 6 SEe/ incident at the peak of the SE yield parameterization. SE is known to be very rad-hard, as used in PMT (50 GRad) and in accelerator beam monitors ($>10^{20}$ mip/cm^2).

On the inner surface of a metal plate in vacuum, which serves as the entrance "window" to a compact vacuum vessel (metal or metal-ceramic), an SE film cathode is analogous to a photocathode, and the shower particles are similar to photons incident. The SEe produced from the top SE surface by the passage of

shower particles, as well as the SEe produced from the passage of the shower particles through the dynodes, are similar to p.e. The SEe are then amplified by sheets of dynodes – metal-meshes or other planar dynodes. The SEe yield is a strong function of momentum, following dE/dx as in the Sternglass formula. On the other hand, as the shower is fully absorbed, those yields rise to about 6-7 at low energies. This variation with particle energy gives rise to quasi-compensation effects as the low energy nuclear fragments of hadron showers have high yields: for example 1 MeV alpha particle produces ~20 SEe. We emphasize the comparison between SEe and p.e. – both are the result of dynode amplification; in a scintillation calorimeter, many photons are made per GeV, but typically only ~1-0.1 % are collected and converted to p.e.; in an SE calorimeter, relatively few SE electrons from the shower particles are generated as the showers pass through the dynodes, but essentially all those SEe are amplified by the downstream dynodes. The statistics of p.e. and SEe are similar.

The construction requirements for an SE Sensor Module are much easier than a PMT, since:

1. The entire final assembly can be done in air. Dynodes used as particle detectors in Mass Spectrometers or in beam monitors cycle to air repeatedly.
2. There are no critically controlled thin film vacuum depositions for photocathode. Other required vacuum activation is not necessary (although possibly desired for enhanced performance).
3. Bake-out can be at refractory temperatures, unlike a photocathode which degrades at T>300°C;
4. The SE module is sealed by normal vacuum techniques (welding, brazing, diffusion-bonding or other high temperature joining), with a simple final heated vacuum pump-out and tip-off.
5. The vacuum necessary is 100 times higher than that needed for a PMT cathode.

The modules envisioned are compact, high gain, high speed, exceptionally radiation damage resistant, rugged, and cost effective, and can be fabricated in arbitrary tileable shapes. The SE sensor module anodes can be segmented transversely to sizes appropriate to reconstruct electromagnetic cores with high precision. Detailed GEANT4 simulations estimated between 35-50 (7-10) Secondary Emission electrons per GeV in a 1(5) cm sampling Cu calorimeter. . The gain per SEe is estimated to be >10^5, and the response close to compensating with an e/pi<1.2. The calorimeter pulse width is estimated to be <15 ns.

A first prototype was built using arrays of mesh dynode PMTs with the photocathodes deactivated. Figure 1 shows a picture of the readout board and the mesh dynode PMTs (top) as well as a sketch of the test beam setup (bottom). 80 GeV electron showers were not contained both laterally and

longitudinally. However, the analysis of the data yields a satisfactory matching of the data and simulations [2].
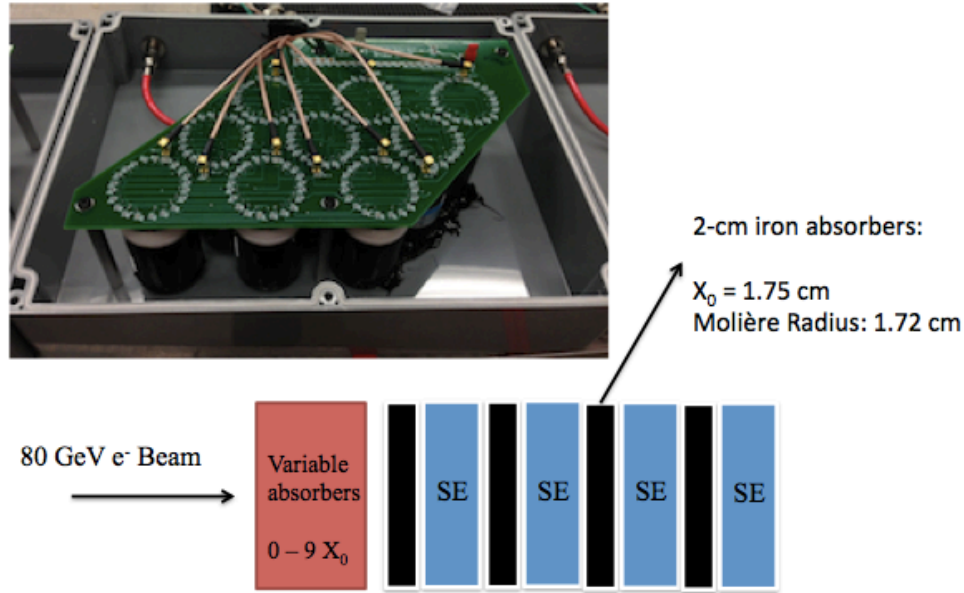

Figure 1. First generation SE module (top) and a sketch of the test beam setup (bottom). Due to the thickness of the active layers (around 9 cm) and the lateral coverage of the active surfaces, the showers were not contained both longitudinally and laterally in the prototype module.

The second-generation prototype, which utilizes improved lateral coverage was produced and tested in the Fermilab test beam. Figure 2 shows a second-generation SE board. The board is designed to house 7 SE detectors in a closest-packed structure. The readout boards of both generations were designed by the graduate students in the University of Iowa group. The analysis of the data is ongoing.

Once the concept is validated, the project will proceed with the construction and testing of a larger module with continuous lateral coverage. The active element will be 15 cm x 15 cm (or 20 cm x 20 cm) read out with on-board analog ADC chips. The segmentation of the detector planes will be optimized based on the cost. The first prototype is designed to have 16 readout channels each covering an area of 5 cm x 5 cm. Figure 3 shows the sketch of such an SE module design. The final parameters will be determined from the results of the second-generation SE module beam tests data analysis results.

Upon optimization of the parameters based on actual EIC environment conditions and considering mechanical and cost factors, photon separation at the order of Moliere radius would be achievable in the forward region with a Secondary Emission Electromagnetic calorimeter. This would also enable the physics calibration of the SE modules with the forward π^0s which are copiously produced,

hence a dedicated calibration system would not be necessary. With sufficient segmentation (upon optimization), the SE calorimeter would not need a pre-shower detector.
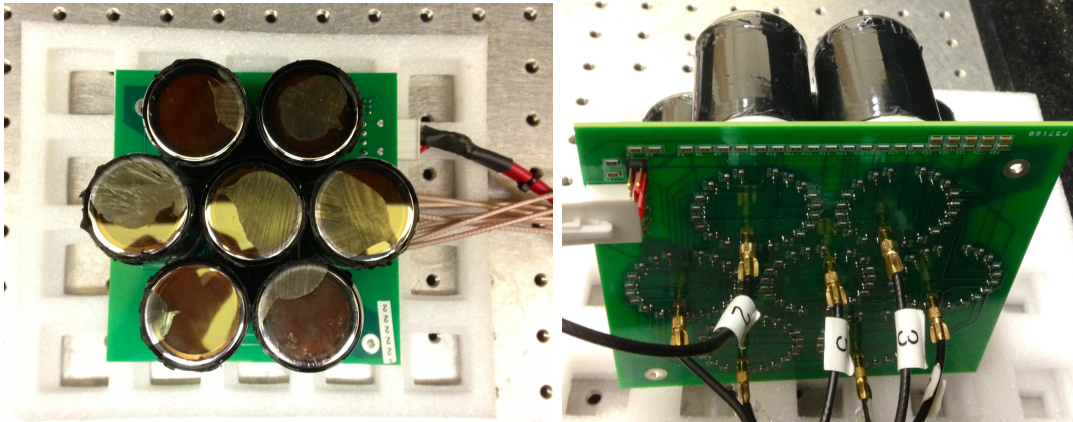

Figure 2. A second-generation SE board with 7 SE detectors, front (left) and back (right) view.
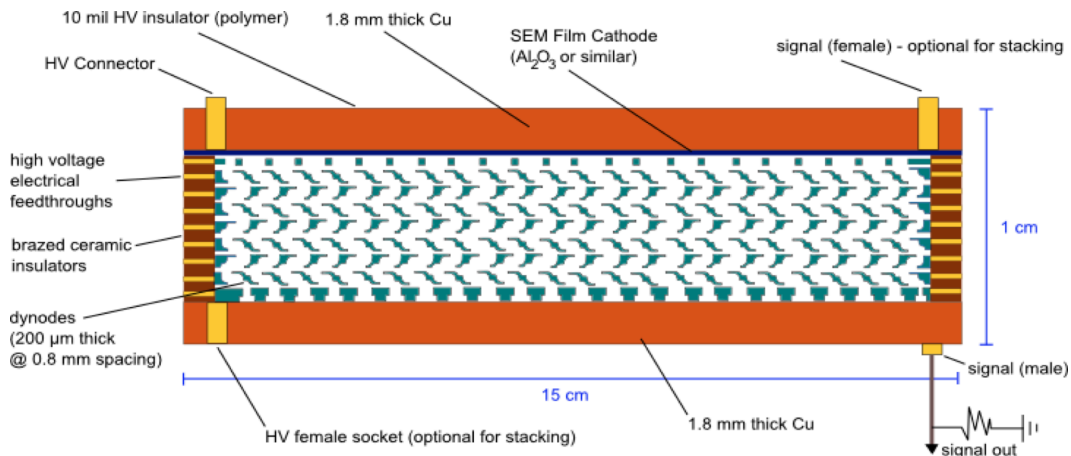

Figure 3. A sketch of the proposed Secondary Emission Calorimeter Module, using etched metal sheet dynodes similar to those used by Hamamatsu. Commercial Cu-Be meshes are also possible and low cost.

3. Zero Degree Calorimeter

We would like to investigate the possibility of optimizing a quartz fiber calorimeter, a quartz and scintillating fiber dual readout calorimeter, and a sampling calorimeter using doped/coated quartz plates and/or secondary emission modules. The University of Iowa group constructed prototypes of all the mentioned options in the past. However, a detailed study of feasibility for the EIC conditions was not performed so far. We would like to support a graduate student to perform detailed simulations.

4. Forward Tracking with RPCs

We would like to investigate the possibility of utilizing RPCs (Resistive Plate Chambers) in the forward region as an alternative to GEMs (Gas Electron Multipliers). As the CALICE DHCAL (Digital Hadron Calorimeter) collaboration centered at Argonne National Laboratory, we designed, constructed and tested the digital hadron calorimeter prototype which utilizes RPCs as active medium and a 1-bit resolution (hence the name digital) readout of 1 cm x 1 cm lateral size pads [3-8]. With an efficient optimization of the pad size, the momentum resolution of the central tracker can be approached. The preference towards the RPCs is because the RPCs are simple in design, robust, reliable (when utilizing glass as resistive plates), and cheap, and their readout can be segmented into small pads.

However, the RPCs need further R&D in order to be proposed for tracking implementations in the EIC conditions. RPCs are known to have low rate capability, at the order of a few hundred Hz/cm^2. This is mainly controlled by the resistivity of the RPC glass. We would like to develop low resistivity glass with the optimum resistivity to allow larger counting rates but still have the desirable RPC performance. The recent developments by the COE College show that resistivities at the order of 10^7 and 10^3 Ω/cm^2 can be acquired with iron and copper doped lead vanadates. A first round of production proved the feasibility of the production process and of the possibility of building an operational RPC with these new samples. Figure 4 shows the RPC built with these first samples.

The new glass is expected to be available in large sheets and to be affordable, albeit more expensive than the current float glass. If this project is successful, it will constitute a breakthrough in RPC technology, rendering the use of troublesome Bakelite as resistive plates obsolete.
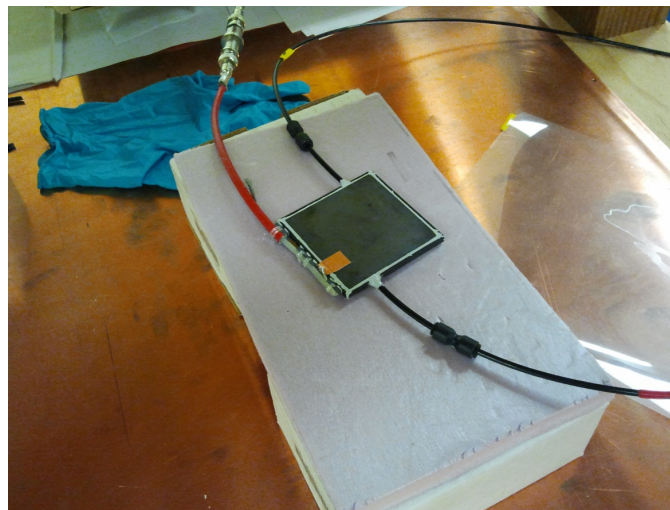

Figure 4. The RPC built with the first samples of the low-resistivity glass.

5. Quartz-Based Particle ID

We would like to investigate the possibility of using quartz variants with different dopes, thicknesses, index of refractions and coatings as effective Čerenkov radiators that would be useful for particle ID both for the barrel and the forward regions. The final proposal is expected to include a stack of different quartz layers coupled to arrays of SiPMs either directly or through fiber systems. We are in close collaboration with the COE College in Iowa on the glass production. COE College has dedicated laboratory facilities and an extensive experience in tuning the specifications of glasses using specific dopes. We are also collaborating with Fermilab for special optical coatings.

6. Budget Request and Justification

Material: At this initial stage of the detector R&D for the EIC, we would like to request funding for the construction of the first dedicated Secondary Emission module with continuous lateral coverage including the readout. We also request funding for special glass production/purchase.

Effort: We would like to request funding for two half time graduate student salaries for the simulation of different design concepts. They are expected to perform both standalone simulations of the detector designs and realistic response analysis using events generated for the EIC. We would like to request RACF cluster accounts for these students and access rights to the generated Pythia samples. The funding request for the Secondary Emission module construction and glass production/coating effort is also included in this proposal. There is no test beam funding request at this stage.

Below table summarizes the funding request:

Table 1. University of Iowa Budget Request

Item	Cost
Secondary Emission Module	$12K
High Rate RPC Glass Production	$5K
Production and Tests of Čerenkov Radiators	$3K
2 x 1/2 Graduate Students	$15K
Total	**$35K**

References

1. S. Chatrchyan et al., "The CMS experiment at the CERN LHC", JINST 3 S08004, 2008.

2. D. Winn, CHEF 2013, Secondary Emission Calorimetry R&D, https://indico.in2p3.fr/getFile.py/access?contribId=49&sessionId=23&resId=0&materialId=slides&confId=7691 .

3. G.Drake et al., "Resistive Plate Chambers for hadron calorimetry: Tests with analog readout", Nucl. Instrum. Meth, **A578**, 88-97 (2007).

4. B. Bilki et.al., "Calibration of a digital hadron calorimeter with muons", JINST 3 P05001, 2008.

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